N72 30775

NASA TECHNICAL MEMORANDUM

NASA TM X-68121

NASA TM X-68121

THE NASA QUIET ENGINES

by Carl C. Ciepluch
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at INTER-NOISE 72
sponsored by the Institute of Noise Control Engineering
Washington, D.C., October 4-6, 1972

THE NASA QUIET ENGINES

by Carl C. Ciepluch
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

INTRODUCTION

In order to help relieve the airport community noise problem NASA initiated the Quiet Engine Program several years ago. The objective of the program was to develop engine noise reduction technology suitable for use on subsonic, conventional-takeoff and landing-type aircraft. Significant test results have recently been obtained with the two experimental Quiet Engines built in this program. The Quiet Engine Program and the recent test results are the subject of this paper.

DISCUSSION

Noise Sources

The turbofan engine, which is the type of engine commonly used in the current transport fleet, has two major noise sources. These noise sources, which are illustrated in figure 1, are jet noise and turbomachinery noise. Let's discuss jet noise first. The turbofan engine has two exhaust jets. One is the result of the air flowing through the engine core. The second is due to bypass air or air pumped by the fan around the engine core. The core jet noise is generally dominant because the core jet is usually of higher velocity and jet noise is primarily a function of jet velocity. Since the jet noise is caused by the turbulent mixing of the jet with the ambient air and this mixing takes place some distance downstream of the engine, it is very difficult and generally impractical to employ acoustic treatment to suppress this type of noise.

The turbomachinery noise is a result of the unsteady flow processes and/or shock waves that occur locally internal to the machinery. Because the fan is the largest machinery component in the engine, it is the largest noise source. Secondary sources are the engine core compressor and turbine. Since machinery noise is generated internally and has to escape through the engine inlet or exhaust nozzles, it is more amenable to acoustic suppression.

Quiet Engine Design Features

A number of noise reduction features were incorporated into the Quiet Engines as shown in figure 2. A high bypass ratio engine was chosen to reduce jet velocity and consequently jet noise and to obtain near optimum performance. Other features incorporated for fan noise reduction were as follows: A relatively large rotor-stator spacing of 2 rotor chords was employed. Reference 1 indicates that increasing the spacing from 0.15 to 2.0 rotor chords reduces sideline maximum noise by 5-6 PNdB. A choice of rotor tip speeds was available for the fan design. Low tip speeds have been found to produce less noise while high tip speed fans can improve airplane economics by reducing engine weight, but they require additional noise suppression to achieve equally low noise output. Both approaches were evaluated in the program. Finally, a noise-governed optimum ratio of fan stator to rotor blades was employed. This ratio was 2.25. In addition to design features aimed at low fan noise production, the fan noise can be reduced further by the addition of sound absorbing liners to the inlet and outlet ducts. This was also done for the Quiet Engines.

Overall Quiet Engine Program

In figure 3 the major elements of the Quiet Engine program are presented along with a schedule. Following several Quiet Engine design studies, a contract with the General

E-7086

Electric Company was initiated in mid 1969 for the design, fabrication and testing of two Quiet Engines. A major part of the General Electric effort included the design, fabrication and testing of three full-scale fans. This was done in order to provide the best fans considering both aerodynamic and acoustic performance. Engine A contained the low speed "A" fan and Engine C incorporated the high speed "C" fan. Both engines are undergoing test programs that include aerodynamic and noise tests at General Electric and additional noise and altitude performance testing at the Lewis Research Center. In parallel with the engine program a contract with the Boeing Company, Wichita Division, was initiated to provide NASA with an acoustically treated, flight-type nacelle for Engine A. Initial tests have been conducted with this nacelle at Lewis.

Quiet Engine Test Results

In the following discussion some of the test results that have been obtained with the two Quiet Engines are presented. Data will be presented for both the baseline or unsuppressed engines and for Engine A with the acoustic nacelle added.

Baseline engines. - The two baseline Quiet Engines have been tested at the General Electric test facilities. A photograph of this facility with Engine A installed is shown in figure 4. The tall structures in the foreground and background are used to support the microphones used to measure engine noise and they are located on a 150 ft arc around the engine. A cross-section of the baseline Quiet Engine configuration is shown in figure 5. This configuration includes a simple bell-mouth type inlet. A small amount of acoustic treatment is built into the engine frame in the immediate vicinity of the fan and engine core compressor inlet. The treatment is of the resonator multiple-degree-of-freedom type as shown inset in the figure.

The aerodynamic characteristics of the two Quiet Engines are shown in figure 6. For comparison the JT3D engine is included. This is the engine that is used in the later versions of the Boeing 707 and DC-8 type transports. It can be seen that the thrust levels of the Quiet Engines are slightly higher but in the same class as the JT3D used in the Boeing 707 and DC-8 airplanes. A major difference is noted in bypass ratio where the Quiet Engines are in the range of 5 to 6 while that of the JT3D is about 1.4. The core jet velocities of the Quiet Engines are seen to be about 2/3 to 1/2 of that of the JT3D.

A comparison of the perceived noise directivity of the two baseline Quiet Engines is shown in figure 7 for the approach speed condition. As noted in the figure the noise levels are nearly identical. However, if we compare them at the takeoff engine speed, as shown in figure 8, there is a significant difference. The high speed engine (C) is front end noise dominated where as engine A is back-end noise dominated. The Engine C perceived noise level is greater by a maximum of 7 dB in the front end and about 3 dB overall. The reason for the higher front end noise at takeoff engine speed for engine C is the supersonic relative speed of fan rotor tips. The resulting shocks formed at the blade tips produce a "multiple pure tone" noise that adds significantly to the front end noise level. A more detailed discussion of multiple pure tone noise generation can be found in reference 2. The high speed engine, therefore, will require additional acoustic treatment in order to bring its noise level down to that of the low speed engine. Future testing with engine C will determine the extent of this treatment penalty.

Engine A with acoustic nacelle. - A cross-section showing engine A with the acoustic nacelle added is shown in figure 9. The nacelle has a flight-type inlet and acoustic treatment on the fan inlet and outlet duct walls. In addition, three acoustically treated splitters are located in the fan inlet and one in the outlet duct. The total weight added to the engine by the acoustic treatment is about 1500 pounds. However, in a flight-weight design the weight increment could be reduced by as much as 50 percent. A photograph of engine A with the Boeing acoustic nacelle is shown in figure 10. The engine and nacelle are shown mounted in the thrust stand of the Lewis engine noise test facility. The inlet rings and center body are observable in the photograph. A comparison of the perceived noise directivity of engine A in the baseline configuration and with the acoustic nacelle added is shown in figure 11 for the takeoff engine speed. The maximum noise level of the baseline configuration is 98 PNdB at the 120° angle. It can be seen that the acoustic treatment reduces the maximum noise levels by 6-7 PNdB. In the front end of the engine the reduction is greater and it amounts to 10 PNdB. Reductions in perceived noise for the approach speed condition were quite similar. A comparison of sound pressure level spectra is useful for making a more detailed evaluation of the performance of the acoustic treatment. This type of plot is shown in figure 12 for the 50°

angle to the inlet position. It can be seen that below a 500 hertz frequency the acoustic treatment does not reduce the noise level. This is as expected since this low frequency range is presumably controlled by jet noise. However, above 500 hertz where the fan noise is usually dominant the acoustic treatment is seen to significantly reduce the noise levels. For example, the blade-passage-frequency tone which occurs at 2000 hertz has been completely removed from the spectrum; this amounts to at least an 18 dB reduction in sound pressure level. The absence of the annoying fan tone is also apparent to listeners who observe the engine during test. Additionally a 5 to 10 dB reduction is noted in fan broadband noise. Therefore, the acoustic performance of the nacelle appears to be quite effective.

In addition to acoustic performance the affect that the treatment has on the engine aerodynamic performance is also of importance. In figure 13 the effect the acoustic treatment has on engine thrust is presented. The upper curve is the baseline or untreated configuration while the lower curve is for the acoustically treated nacelle. A reduction in engine thrust, which amounts to 5 percent at the takeoff speed of 3260 rpm, results when the acoustic treatment is added. Accordingly, airplane economics will be adversely affected due to the performance loss and also the weight increase associated with the use of large amounts of acoustic treatment. An estimate of the economic penalty was made for a 3-engine, medium range transport, and it was found that the acoustic treatment configuration used in these tests would increase airplane "direct operating costs" by about 5 percent. Lesser amounts of treatment would, of course, result in a smaller economic penalty.

Flyover Noise Comparison

It is interesting to estimate what impact the Quiet Engine technology would have if it were employed on typical current aircraft. Calculations of this nature were made and the results are shown in figure 14 and they are also compared to a typical four engine aircraft and the current FAA noise regulations. The noise levels are presented in terms of the standard FAA noise measuring unit. This noise unit is referred to as "effective perceived noise level" or EPNdB. The data are presented for the standard FAA noise measuring stations of takeoff and landing. It can be seen that the DC-8 type aircraft noise levels are substantially above the FAA's FAR-36 noise regulation for new aircraft of this weight. When the noise level for a DC-8 aircraft is calculated with flight weight untreated Quiet Engines, FAR-36 regulations are surpassed by 7 or 8 dB. These noise levels are also noted to be about 20 dB below the current DC-8 noise levels. Further if an acoustically treated nacelle is added to the Quiet Engines, the aircraft produces an additional 7 dB less noise. For the later case the noise levels are about 15 dB below FAA noise regulations.

CONCLUSIONS

The major conclusions that can be drawn from the Quiet Engine Program are as follows:

1. Most importantly we have developed and demonstrated engine noise reduction technology which, if applied to future aircraft, can bring about a substantial reduction in aircraft noise levels.

2. There will be an associated airplane economic penalty which, we will be studying in more detail in the future and hope to be able to reduce.

3. We are encountering new noise floors, as engine noise levels are lowered, towards which our future research can be directed in order to make further progress in aircraft noise reduction.

4. And finally, the information we have generated in the program will be useful in establishing future aircraft noise regulations.

REFERENCES

1. Benzakein, M. J.; and Kazin, S. B.: Some Experimental Results on Lift Fan Noise Reduction. Paper 71-743, AIAA, June 1971.

2. Kramer, James J.; Hartmann, Melvin J.; Leonard, Bruce R.; Klapproth, Jack F.; and Sofrin, Thomas G.: Fan Noise and Performance. Aircraft Engine Noise Reduction. NASA SP-311, 1972, pp. 7-61.

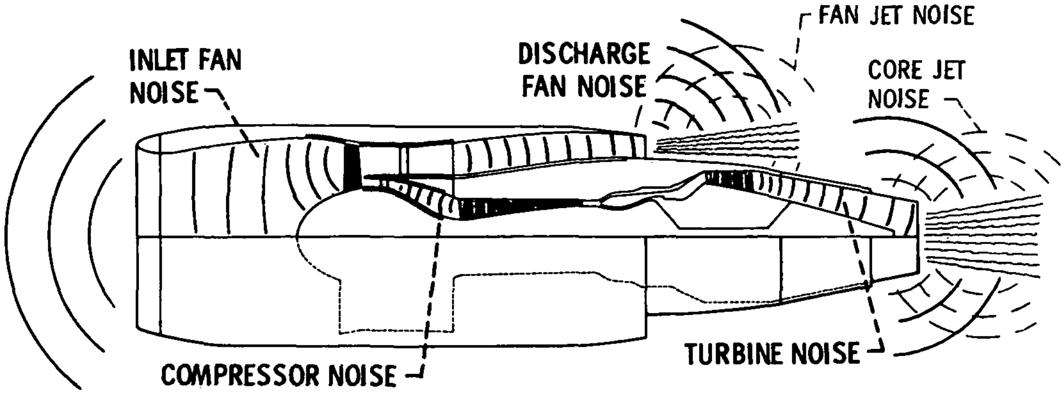


Figure 1. - Turbofan noise sources.

E-7086

JET NOISE

HIGH BYPASS RATIO 5-6, GIVES LOW JET VELOCITY & LOW JET NOISE

FAN SOURCE NOISE

LARGE SPACING BETWEEN FAN ROTOR & STATOR; REDUCES INTERACTION NOISE

LOW TIP SPEED, 1160 FT/SEC, REDUCES FAN NOISE PRODUCTION

HIGH TIP SPEED FAN, 1550 FT/SEC, REQUIRES ADDITIONAL SUPPRESSION FOR LOW NOISE BUT IMPROVES ENGINE WEIGHT

OPTIMUM RATIO OF FAN STATOR TO ROTOR BLADES

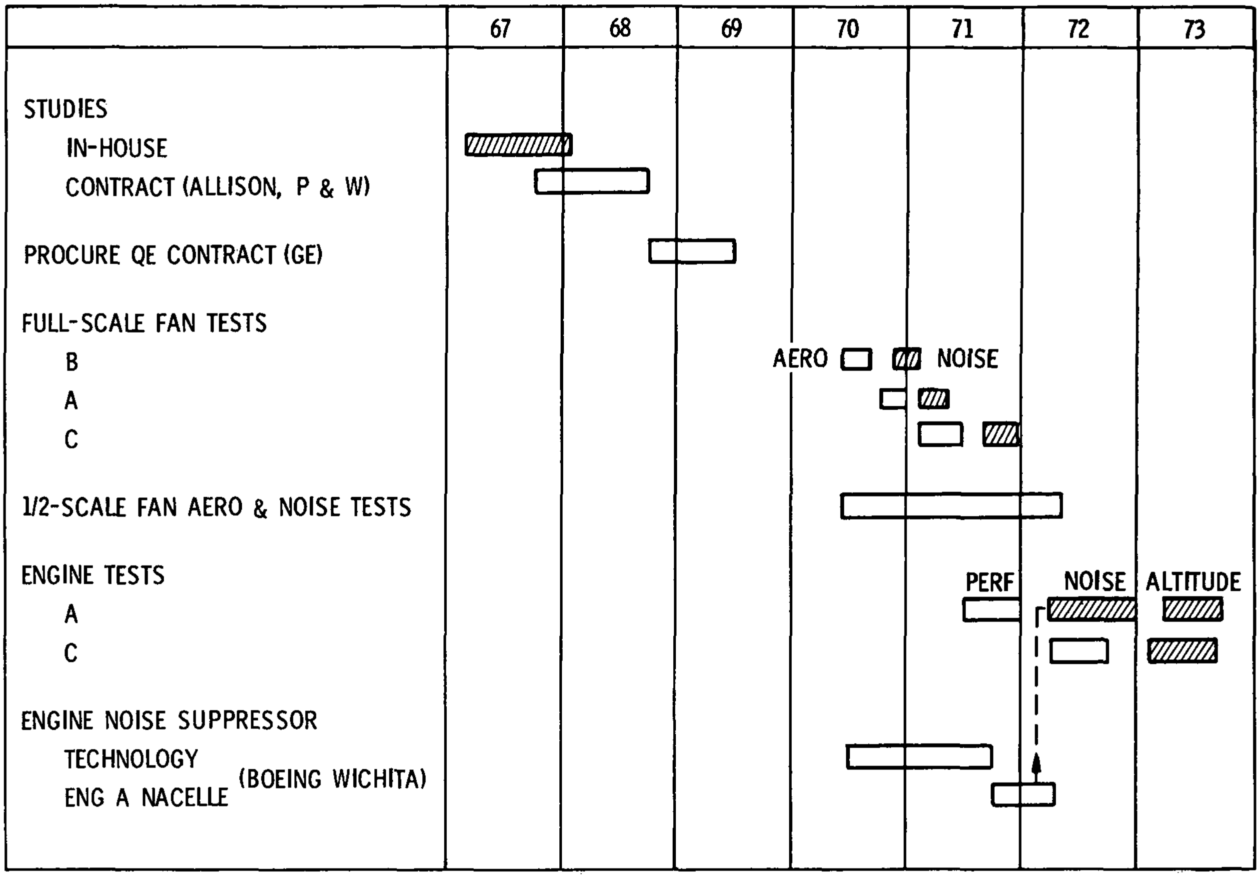
FAN NOISE SUPPRESSION

SOUND ABSORBING LINERS IN FAN INLET & DISCHARGE DUCTS

CS-64046

Figure 2. - Quiet engine design features.

E 7086



CS-61664

Figure 3. - Quiet engine program.

E-7086

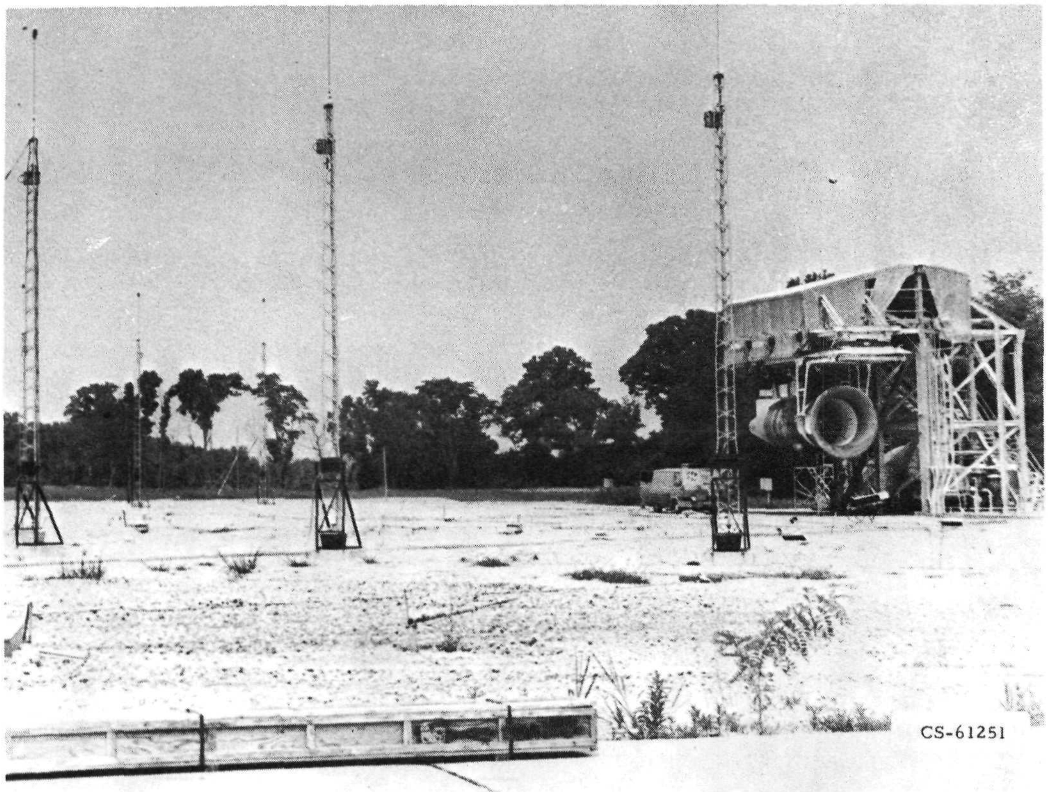


Figure 4. - Engine A on test.

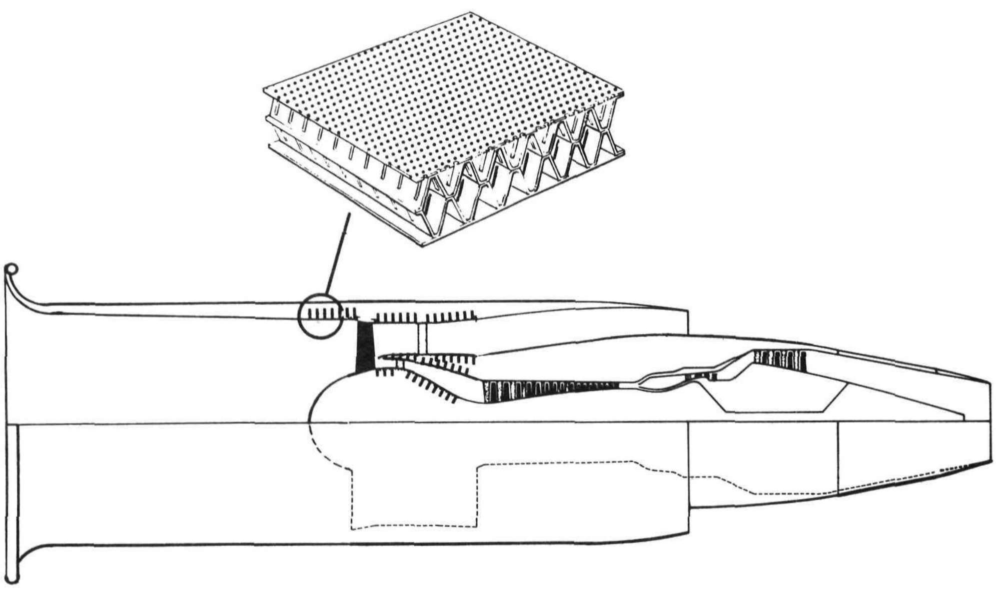


Figure 5. - Quiet engine A baseline configuration.

CS-63322

ENGINE	QE-A	QE-C	JT3D
CRUISE THRUST, LB	4 900	4 900	4 450
TAKEOFF THRUST, LB	22 000	22 000	18 000
FAN TIP SPEED, CRUISE	1 160	1 550	1 430
FAN PRESSURE RATIO, CRUISE	1.5	1.66	1.74
BYPASS RATIO, CRUISE, FT/SEC	6.1	5.1	1.42
CORE JET VELOCITY, FT/SEC	1 180	850	1 600

CS-63209

Figure 6. - Engine characteristics.

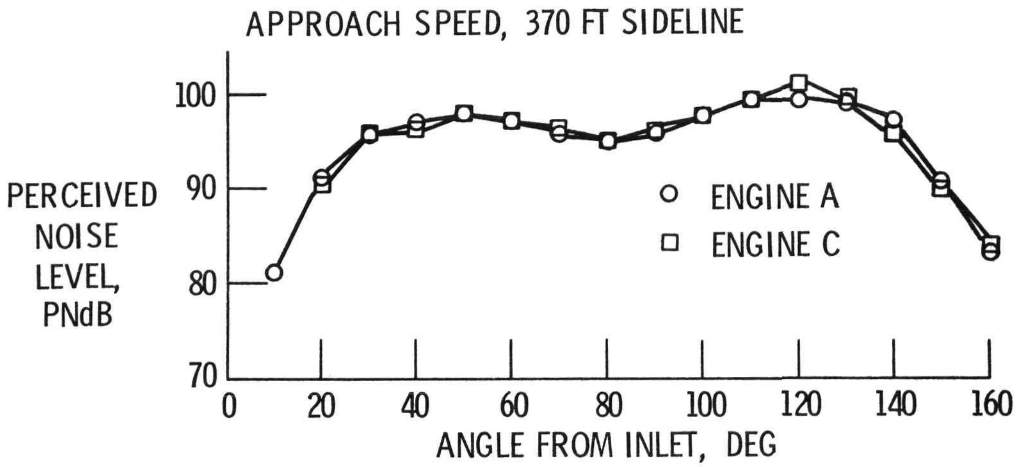


Figure 7. - Baseline engine perceived noise directivity.

CS-63384

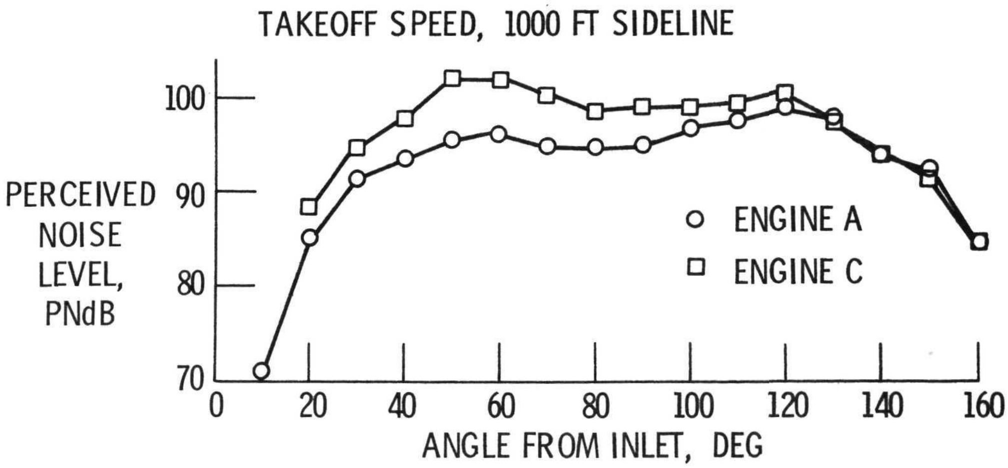
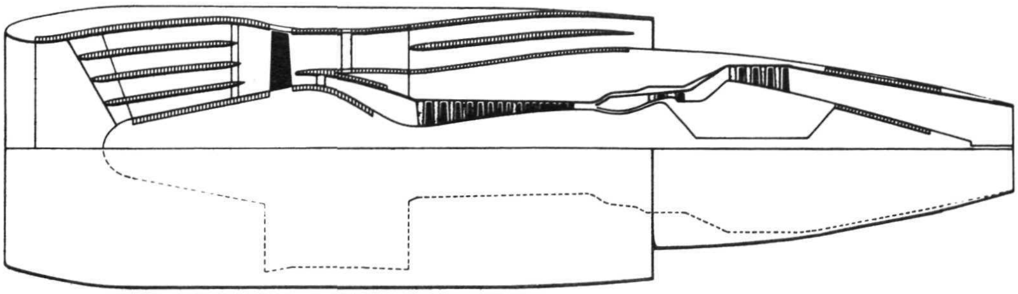


Figure 8. - Baseline engine perceived noise directivity.

CS-63390

E-7086



NACELLE ACOUSTIC TREATMENT

	INLET DUCT	EXHAUST DUCT
AREA, SQ FT	353	362
WEIGHT, LB	846	666

Figure 9. - Quiet engine A with acoustic nacelle. 63321

E-7086

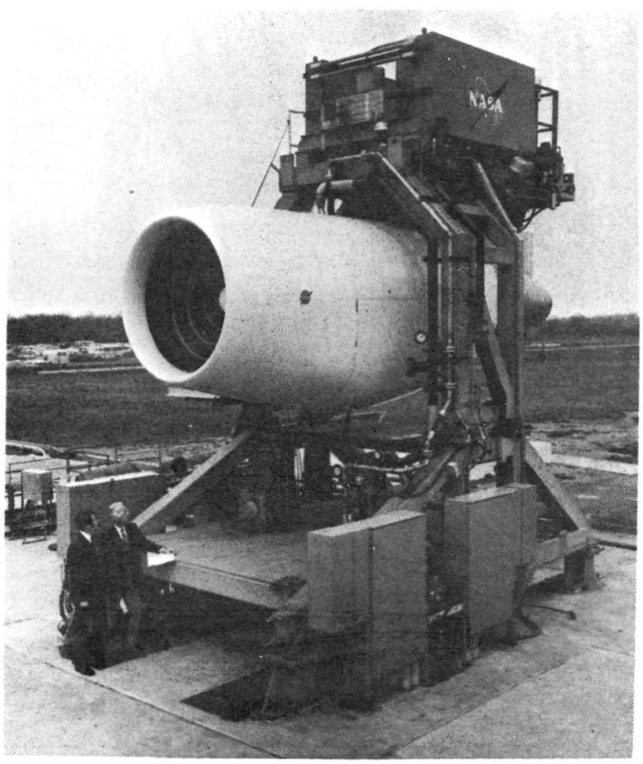


Figure 10. - Quiet engine "A" with acoustic nacelle.

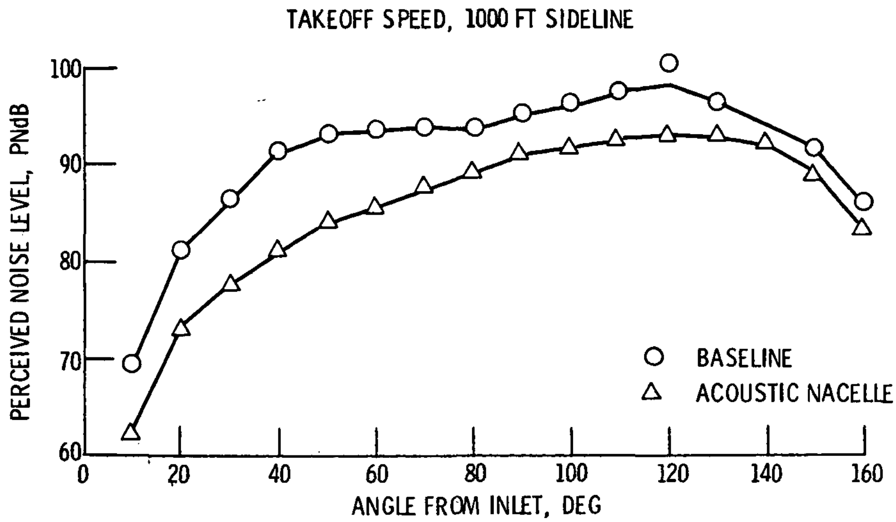


Figure 11. - Quiet engine perceived noise directivity.

E-7086

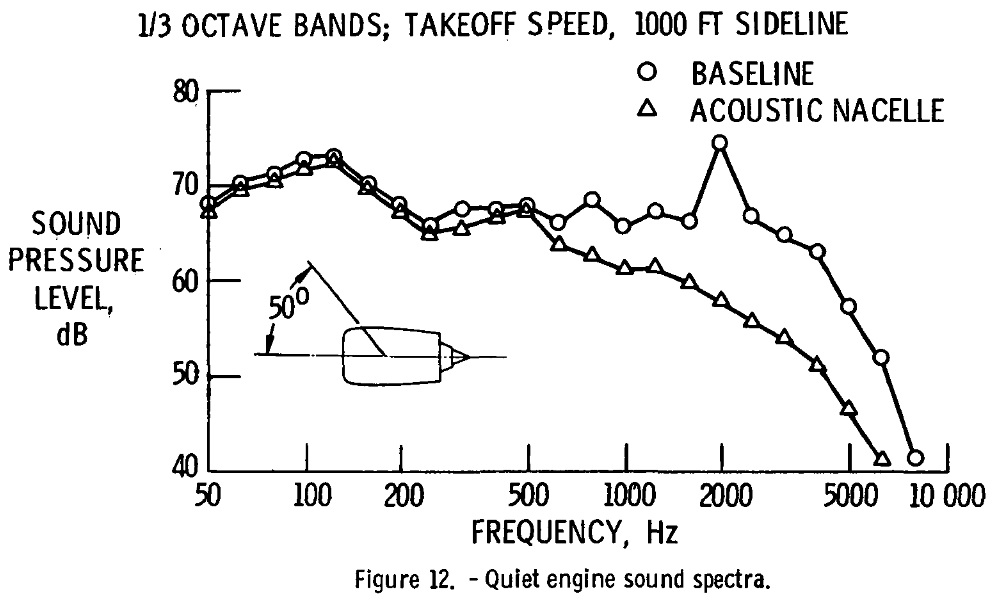
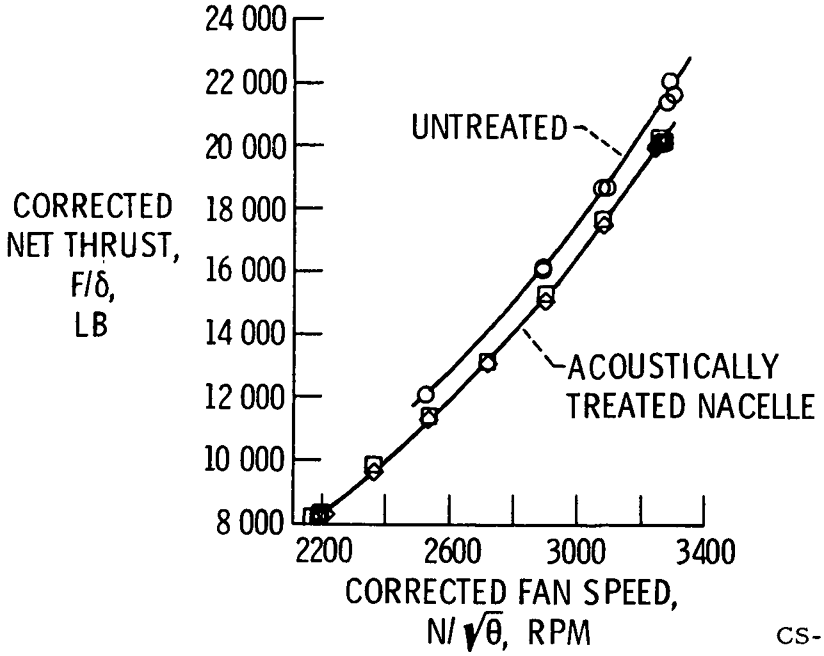


Figure 12. - Quiet engine sound spectra.

CS-63276



CS-63383

Figure 13. - Effect of acoustic treatment on engine "A" thrust.

	TAKEOFF	APPROACH
	EPNdB	
DC-8	116	118
FAR-36	104	106
BASELINE QUIET ENGINE A	97	98
QUIET ENGINE A WITH ACOUSTIC NACELLE	90	89

Figure 14. - Flyover noise comparison. CS-63277

E-7086